

Observations of 5–25 MeV albedo electrons at Hyderabad

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Abstract : Observations of splash and re-entrant electrons in 5–25 MeV range have been made in the upper atmosphere using high altitude balloon from Hyderabad, India, using a bi-directional charged particle telescope capable of discriminating electrons from other singly charged particles. The energy resolution of the telescope was ~ 1 MeV and the geometrical factor was 15.6 cm sq sr for both the telescopes. The measured spectra are well within the upper limit set by the measurements at higher latitudes. The measured spectra are compared with the theoretically calculated spectrum. The splash and re-entrant electron spectrum can be represented by power laws:

$$\left| \frac{dJ}{dE} \right|_{\text{sp-al}} = (9.1 \pm 2.0) 10^2 (50 + E)^{-(1.6 \pm 0.5)} [\text{m}^2 \text{SrMeVSec}]^{-1} [E > 5 \text{ MeV}],$$

$$\left| \frac{dJ}{dE} \right|_{\text{re-al}} = (6.5 \pm 2.0) 10^2 (50 + E)^{-(1.6 \pm 0.5)} [\text{m}^2 \text{SrMeVSec}]^{-1} [E > 5 \text{ MeV}].$$

The shapes of these albedo electron spectra are similar. In both of these spectra deviation from a smooth curve is observed around 10 MeV, which is also discussed.

Keywords : Albedo electrons, balloon experiments, scintillation detectors, charged particle telescope

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1. Introduction

Primary cosmic ray interactions with air nuclei in the earth's atmosphere produce secondary charged particles largely moving in the forward cone of interaction. Some of these particles also move in the backward direction. These backward moving particles called "splash albedo" go out of the atmosphere and guided by the geomagnetic field lines, re-enter the atmosphere as "re-entrant albedo", nearly at the same latitude in the opposite hemisphere. Due to the small energy losses during this traversal the energy spectra of the splash and re-entrant albedo are expected to be similar

Tulinov *et al* [1] suggested that the ionization in the lower ionosphere may be modestly contributed by the albedo particles. Based on their results of the rocket borne experiments it was proposed that the ionization produced in this region by albedo could be somewhat less but comparable to that from the primary cosmic rays or the Lyman- α

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radiations of the Sun, and, may also explain the ion-density decreases of the D-region to a fixed value [2]. The only direct measurements of ionization in the middle atmosphere were made by Neher [3,4] through a series of rocket and balloon borne Ion-chamber experiments. Attempts have been made to theoretically explain this ionization using various known sources of ionization in this region [5,6,7]. The theoretically calculated ionization rates in this region are lower than the observed values as reported by Datta *et al* [5]. The shortfall in the theoretical ionization rates could be filled up by the albedo particles, which were not considered in these theoretical evaluations.

Graser and Schonfelder [8] suggested that the discrepancy between experimental measurements and the estimated production of atmospheric gamma rays from all known sources could possibly be explained by considering the re-entrant albedo electron contribution to the atmospheric gamma rays.

It was therefore considered important to study the albedo electrons in the middle atmosphere using balloon borne experiments in low latitude region. Moreover in order to understand the charged particle phenomenon in the geomagnetic field it would be interesting to observe whether the higher integral flux of primary cosmic rays at the polar latitudes is also reflected in the albedo particle flux at different latitudes or not.

Theoretical evaluation of the flux and energy spectrum of the electrons in atmosphere were attempted by Bhabha [9] using the basic theory of cascades. The results became basis for the later work. Bland [10] derived an upper limit to the intensity of re-entrant electrons near 45 degree geomagnetic latitude. Perola and Scarsi [11] and Verma [12] theoretically estimated the flux and energy spectrum of the secondary electrons. Using pion production spectrum Verma [12] has also given the depth curves at four different geomagnetic locations Hyderabad (India), Texas, South Dakota (USA) and Fort Churchill (Canada). Detailed calculations were carried out by Abraham *et al* [13]. Beurmann [14] and Daniel and Stephens [15]. The flux and spectrum of Abraham *et al* [13] were modified by Bhatnagar and Verma [16] in the low energy region (5–50 MeV) using a single parameter normalization with the measurements of low energy electron flux of Hovestadt and Meyer [17] at Ft. Churchill, yielding the spectrum shown in Figure 1.

In the low latitude equatorial region, only a few authors have reported extensive measurements of the flux and energy spectra of the albedo electrons and protons in the low energy range of our interest (1–100 MeV). In the middle latitudes Verma [18] measured the flux and energy spectrum of the albedo electrons in 10–1100 MeV interval from Palestine, Texas, USA. Israel [19] studied the splash and re-entrant electron spectrum in 12 MeV–1 GeV range from higher latitude of Fort Churchill, Manitoba, Canada, and also from Palestine, Texas, USA. Daniel and Stephens [20] have measured the electron spectrum from Hyderabad, India, above local cutoff energy 15 GeV/c. All these measurements indicate that the slope of the low energy part of the spectrum does not follow the same trend as the higher

energy part. Below 200 MeV the spectrum is somewhat flatter and its slope increases in higher energy region.

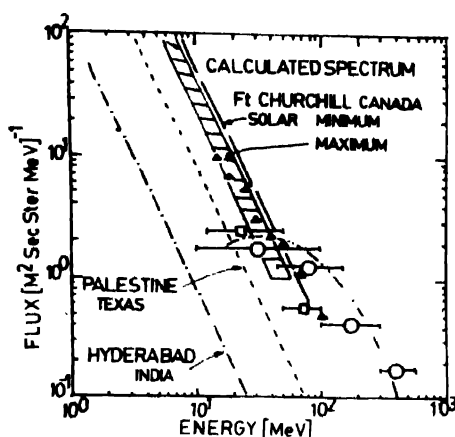


Figure 1. Calculated spectrum of downward moving knock on electrons below 20 MeV at Hyderabad (India), Palestine, Texas (USA), Ft. Churchill (Canada). Shaded region shows the upper and lower limits on the spectrum. The --- curve represents calculated spectrum by π - μ - e decay. Data points are measurements by \blacktriangle Hovestadt and Meyer [17] (Ft. Churchill- \square) Israel [19] (Ft. Churchill) and Verma [18] (Palestine).

Since no measurements of the flux and energy spectrum of low energy albedo electrons are reported from low latitudes, the flux, energy spectra and the angular distribution of the charged albedo particles was required to be studied for understanding the albedo particle physics, the energy deposited by these radiations in middle atmosphere and the chemistry of the lower atmosphere. Though some satellite based measurements are available in this energy interval, most of these being in the geostationary orbits in equatorial region are not applicable to the present investigations. Moreover, the albedo measurements carried out at the balloon altitudes (≈ 40 km) could be extrapolated up to the lower ionosphere regions (≈ 70 km) without any significant change in the spectra [19], owing to the low density of matter in between (4–5 gm/sq cm).

With the aim of studying the energy spectrum of the charged albedo particles an experiment was designed to measure both the splash and re-entrant particles simultaneously using a novel combination of two charged particle telescopes in opposite directions. The telescope was capable of discriminating electrons, muons and protons.

2. The experiment

Cross sectional view of the charged particle telescope developed at the Gujarat University, Ahmedabad is shown in Figure 2. It consists of two telescopes in opposite directions for studying the energy spectrum of the electrons (5 to 25 MeV), muons (17 to 42 MeV) and protons (50 to 120 MeV) with good energy resolution of approximately 1 MeV. The half acceptance angles of both the telescopes are 30 degrees and the geometrical factors are 15.6

cm sq ster. To study the angular distributions of the charged particles the telescope was mounted on a movable platform which was provided with a rotation mechanism around its horizontal axis passing through the central detector [21].

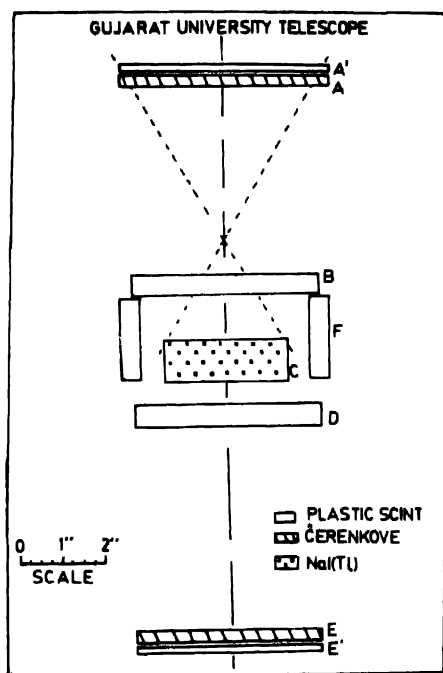


Figure 2. Cross sectional view of the bidirectional Charged Particle Telescope.

Discrimination against nuclear particles was achieved by dE/dx - E technique supported by the energy threshold Cerenkov detector. Using various coincidence and anti-coincidence combinations, particles were electronically identified. Thallium activated Sodium Iodide [NaI (Tl)] scintillator crystal (C in Figure 2) was used for total energy (E) measurements. This detector was of 3 inch diameter and 1 inch thickness. The dE/dx detectors (B and D) were made up of 0.5 inch thick plastic scintillator and the Cerenkov detectors (A and E) were constructed out of 0.25 inch thick acrylic disk. Two thin (0.0125 inch) plastic scintillator detectors (A' and E') defined the geometry of the telescopes. The anti coincidence counter (F) was fabricated in a cylindrical shape from a 1.0 inch thick plastic scintillator.

All the detectors were tested and calibrated using various radioactive sources for their individual characteristics and by ground level penetrating charged particle components *i.e.* muons of the secondary cosmic rays in the laboratory for a period of over a year to establish the linearity and stability of individual detectors and the associated electronic systems [22]. The muon's minimum ionizing peak was utilized to establish the effective discriminator settings in individual channels. The low intensity 8 MeV electron beam from the microtron accelerator of Puna University, Pune, India, was utilized for the calibration of the middle

energy range of the telescopes [23]. These tests show that the efficiency of the Cerenkov detectors for electrons was 99% at 0.5 MeV and improves with increasing energy. The overall efficiency of detection as determined by the muon tests was better than 99%.

The balloon borne electronic system was divided into two functional section viz. the Analog and the Digital subsystems. The analog subsystem is made up of the charged sensitive preamplifiers mounted at the base of the photo multiplier tubes, the post amplifiers, the discriminators and the analog to digital converters (Pulse Height Analyzer) for dE/dx and E detector channels. Outputs of the discriminators were fed to event counters with different scaling factors as well as to the logic circuitry for particle selection, which generated a particle identification tag for each even detected. For every event, the outputs of the 3 PHA's, 15 counters, pressure and temperature information and particle identification tags were latched into the encoder which transmitted this information along with other housekeeping data in serial stream through telemetry transmitter, provided by the National Balloon Facility of TIFR, Bombay.

At the ground station the received information was separated into various components using a microprocessor based quick look analysis system for monitoring the performances of various detectors during flight in real time. Partially-analyzed data like the pulse height information for three channels and count-rates for all detectors were available on demand from the microcomputer on the Teletypewriter console. The data was also recorded on computer compatible tapes for detailed post flight analysis.

3. The flight

The balloon flight from which the results are reported here was conducted from Hyderabad, India (Geomagnetic latitude 11 degrees north) on 8th December 1984. The launch took place at 0523 IST (2353 GMT). The Balloon attained ceiling altitude of 4 mb at 0800 IST and drifted 300 kilometers west in the next 4 hours. The payload was released by command at 1200 IST (0630 GMT).

Due to the low event rates and shorter flight duration, the angular distribution of the albedo electrons was not carried out in this flight.

4. Data analysis

We classify the selected events by presence or absence of signals in selected detector groups, as given in Table 1.

Table 1. Classification of events.

Particle type and direction	Signal in	No Signal in
Downward stopping electrons	A', A, B, C	D, E, E', F
Upward stopping electrons	E', E, D, C	B, A, A', F
Downwards stopping muons or protons	A, B, C	A', D, E, E', F
Upward stopping muons or protons	E, D, C	E', B, A, A', F
Penetrating particles	A', A, B, C, D, E, E'	F

The energy ranges of these particles calculated from the tables of Energy loss are as follows :

Stopping electrons :	5 to 25 MeV,
Stopping muons :	17 to 42 MeV,
Stopping protons :	50 to 120 MeV.

The lower energy threshold was determined by the particles just entering the C detector while the upper energy bound was based on the particles penetrating the C detector.

The data recorded on tapes was off line analyzed on VAX11/730 computer. In the raw data, frames containing transmission errors were separated out by parity checking. Since the event rate was low, there were many repetitive data frames also, which were separated by comparing the event counters of successive frames leaving only one frame of data for every event. Particles of different types identified by their id-codes were pulse height analyzed for various single and double parameter analyses, from where the final spectra were obtained.

An uncertainty correction of 11% was applied to the results to account for the angle of incidence correction and geometrical factor corrections. This was in addition to the statistical corrections [22].

5. Spectrum of splash electrons

At float altitude 1586 events of the upward moving albedo electrons were observed in 253 minute equivalent. The spectrum of vertically upward moving splash albedo electrons, obtained from data in 5 to 24 MeV interval is shown in Figure 3. This spectrum can be represented by a power law

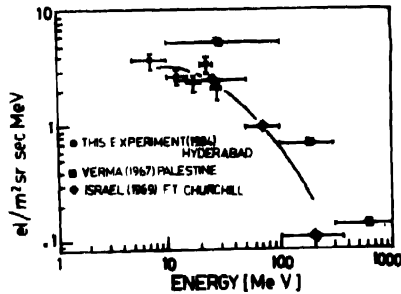


Figure 3. Differential energy spectrum of the Splash electrons in 5–25 MeV interval at 3.2 gm/sq cm at Hyderabad. The solid curve is calculated spectrum from Verma [12]. Other data points are measurements at higher latitudes.

$$\frac{dJ}{dE}_{sp-el} = (9.1 \pm 2.0) 10^2 (50 + E)^{-(1.6 \pm 0.5)} [m^2 \text{ SrMeVSec}]^{-1} [E > 5 \text{ MeV}].$$

The altitude dependence of the splash albedo electron flux indicates a broad hump around 100–200 mb. The electron flux variations between 100 mb and the float altitude were

found to be small. Same is also observed by Verma [18] and Israel [19]. This is due to the fact that the production of secondaries dominates over their absorption at around 150 mb below which about 85% of the atmosphere lies.

6. Spectrum of re-entrant electrons

Local atmospheric secondaries are the major component of downward moving electron flux. Their integral flux reaches a maximum around 200 gm/sq cm depth decreasing on both the sides. Therefore, at the top of the atmosphere the downward moving flux is mainly due to the re-entrant albedo electrons. In our experiment, the downward electron spectrum was studied at the ceiling altitude of 4.0 mb. Due to restriction on selection criterion 93 minutes equivalent of data was used in 5–24 MeV energy interval for the re-entrant albedo studies. Thus energy spectrum of vertically downward moving electrons from 289 events is shown in Figure 4 and can be approximated by the power law as given below

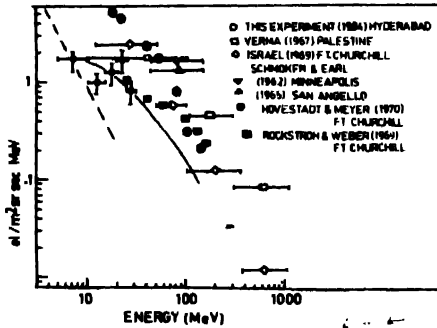


Figure 4. Differential energy spectrum of downward moving electrons in 5–25 MeV energy interval at 3.2 gm/sq cm over Hyderabad. The dashed curve is calculated electron spectrum from knock on process. Solid curve gives the shape of high energy spectrum inferred from Verma [12]. All other measurements are at higher latitudes.

$$\frac{dJ}{dE}_{\text{re-el}} = (6.5 \pm 2.0) 10^2 (50 + E)^{-(1.6 \pm 0.5)} [\text{m}^2 \text{SrMeVSec}]^{-1} [E > 5 \text{ MeV}].$$

The lower flux of albedo electrons at Hyderabad as compared with the fluxes at places of higher latitudes may be explained as geomagnetic latitude dependence. It may be seen from Figure 4 that the measured fluxes of re-entrant albedo electrons at Ft. Churchill vary by a factor of 4–5 which can be attributed to the day–night variations of geomagnetic threshold rigidity and/or solar modulation as discussed by Daniel and Stephens [15].

The theoretical electron spectrum [16] due to knock-on process, which is predominant below 20 MeV energy, is plotted in Figure 5 along with present measurements of splash and re-entrant electrons. The fit to our data points and extrapolation to higher energies is shown by the solid curves as inferred from theoretical and experimental work of Verma [12,18]. The deviation of the measured points from smooth curves around 10 MeV is notable, it could be statistical. Since it is in both the spectra this is unlikely. On of the possibility is that

this could be due to the fact that the probability of electron production by knock-on process is decreasing with increasing energy while the probability of electron production *via* pionization in the nuclear interaction is increasing with energy. The knock-on and nuclear interactions pionization processes have almost equal probabilities at these energies, and these add up.

It should also be noticed from Figure 5 that the shapes of the splash and re-entrant albedo electron spectra are similar, as expected theoretically. The lower intensity of the re-entrant electrons may be due to loss of some splash albedo electrons during transit through magnetosphere. These losses may include the interactions in the residual atmosphere, scattering and trapping in the radiation belts.

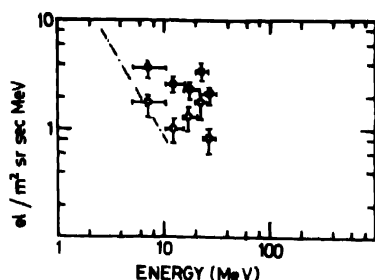


Figure 5. Comparison of the splash and re-entrant electron spectra measured by this experiment.

The observed electron spectra could be used to calculate the energy deposition by the electrons in the middle atmosphere [24]. In these calculations, angular flux distribution of electrons are needed. However, there are no angular distribution measurements, therefore, it is suggested that the angular distribution and the spectra at higher energy region should be studied for a better understanding of the albedo particles and their interactions in magnetosphere and upper atmosphere.

Baker *et al* [25] have shown that the multi MeV magnetospheric electrons precipitating in the atmosphere deposit a large amount of energy in 40-60 km region and this energy may be 3-4 times greater than solar EUV and primary cosmic ray energy deposition. They have calculated the energy deposition from electrons as well as bremsstrahlung X-rays produced by these electrons.

7. Conclusion

We have investigated experimentally the flux and energy spectrum of Splash and Re-entrant albedo electrons in the 5-25 MeV energy region from Hyderabad, India. We have observed that our results are well within the limits put by the measurements at higher latitudes. The measured fluxes also reflect the geomagnetic latitude dependence. The fact that measurements are in the transition region of the knock-on and nuclear interaction processes of electron production is visible in the observed spectrum. These observed vertical flux and energy spectra need to be supplemented with their angular distribution with Zenith angle.

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